New Modalities in Existing Infrastructure

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Executive Summary

Many HEP experimental installations comprise world-class infrastructure for sensitive searches for new physics. After an experiment has achieved its scientific goals, ideally the community would continue to leverage the infrastructure for future experiments. The simplest case of this general principle is perhaps that of upgrading an existing experiment. Previous examples include KamLAND => KamLAND-Zen, and the Darkside installation in the former CTF (Counting Test Facility). There are many liquid noble installations around the world that can lend themselves to this sort of upgrade. As one example, the DEAP-3600 experiment is currently undergoing hardware upgrades for improved background rejection with future potential uses of the experimental infrastructure after the science run including a sensitive assay of 42Ar in underground argon or measurements of solar neutrinos.

Here, we describe as a case study two new ideas for upgrades of the LZ detector, after it completes its scientific goals in ~2027. The specific proposals are called HydroX and CrystaLiZe, both of which would benefit from leveraging the low-background installation with water tank shielding and liquid scintillator veto detectors, as well as the associated infrastructure. However, both would also require significant upgrades or modifications to the LZ inner detector. We described each briefly in turn.

HydroX - The idea behind HydroX is to add hydrogen to LZ to enable searches for very light dark matter. Hydrogen is the ideal target for low mass dark matter because it has the lowest atomic number of any element, and because its unpaired proton (or neutron in the case of deuterium) provides sensitivity to spin dependent couplings in the low mass range. As an upgrade for LZ, HydroX would leverage the major investment in the low background construction and radio-clean environment. Significant R&D is still required to demonstrate the viability of this idea, primarily measuring detector properties of H-doped liquid xenon, including the signal yields of proton, electron, and xenon recoils, and understanding the cryogenics of H-doped LXe. A HydroX-like upgrade could also be envisioned for next generation dark matter efforts.

CrystaLiZe - this is a proposal to crystallize the liquid xenon target of the LZ instrument. R&D is underway to demonstrate the feasibility of this plan. If it works, it would enable full tagging of radon-chain beta decay backgrounds, enabling crystaLiZe to be a neutrino-limited (rather than radon-limited) dark matter search. As with HydroX, this path forward would leverage the LZ infrastructure after LZ completes its science goals (~2027). A fundamental premise of this

proposal is that crystalline xenon will have “the same” particle detection properties as does liquid xenon. Preliminary work shows the scintillation yields are identical. Next steps intend to confirm that the incident particle type discrimination is, too.

A key point is that HydroX and CrystaLiZe appear to be fundamentally compatible with each other, that is, one could imagine doping a light element into a crystalline xenon target.

Instrumentation requirements to achieve physics goals (list)

- Ability to separate light gases from xenon to better than 1 part in 1000 from a high initial gas concentration
- Ability to dissolve light gases into xenon at the percent level without inducing a phase change or excess bubbling
- Introduction and separation of non-condensable gases in liquid xenon
- Photosensors that are robust to a non-negligible atmosphere of light gases such as hydrogen or helium
- Photosensors that can detect 140 nm scintillation (from crystalline xenon)

Significant instrumentation challenges (list)

- Cryogenic engineering to maintain thermodynamic control of a gas/liquid mixture or of xenon ice
- Calibration of a threshold detector at very low energy, with neutrons, betas, gammas
- Control of phase change dynamics: transition to frozen state without inducing fractures

Relevant physics areas (e.g., low-mass DM, solar neutrino oscillations, CEvNS)

- Dark Matter Direct Detection
    - High exposure weak-scale dark matter (to the neutrino fog)
    - Spin-independent 0.1-10 GeV searches to the SI solar neutrino fog
    - Proton scattering (spin-dependent) 0.1-10 GeV searches with no neutrino fog, due to the near-zero weak charge of the proton
    - Neutron scattering (spin-dependent) 0.1-10 GeV searches
- Solar neutrino detection, particular pp-solar neutrinos

Relevant cross-connections (e.g., other topical groups, other white papers)

- CF1
  - Solicited white paper 1 - “Direct Detection to the Neutrino Floor”
  - Solicited white paper 2 - “The landscape of low threshold direct detection in the next decade”
- Underground facilities

Further reading (e.g., reference for existing TDR, reference paper, conference proceedings,)

- The LUX-ZEPLIN (LZ) Experiment - https://doi.org/10.1016/j.nima.2019.163047
- The LUX-ZEPLIN Technical Design Report - https://arxiv.org/abs/1703.09144
- Projected WIMP sensitivity of the LUX-ZEPLIN (LZ) dark matter experiment - https://doi.org/10.1103/PhysRevD.101.052002
- R&D towards hydrogen-doped LXe TPCs - Alissa Monte, DPF 2019